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LIGNIN: An Inviting Storehouse Page 1

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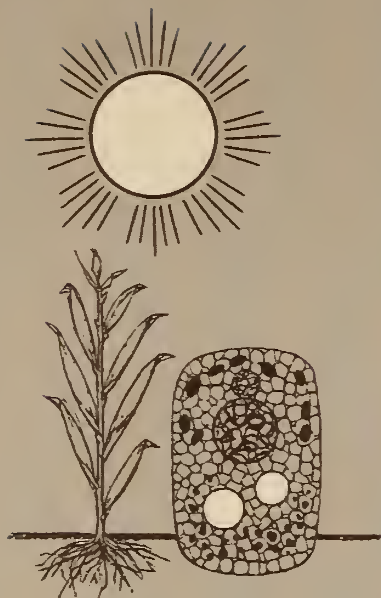
Index Issue



AGRICULTURAL SCIENCE REVIEW

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Where Are The Eccentrics?

Even a casual review of the history of science will reveal the fact that many of our great scientists were nonconformists—not only by the standards of their own era, but also from the present day viewpoint. Pasteur and Einstein were typical examples of the many who liked to work in isolation. Copernicus, in his rare idle moments, liked to paint portraits of himself. Edison disdained regularity in sleeping and eating. Galileo wrote his best papers in the form of dialogs. Lavoisier's contempt for those who wouldn't believe in him cost him his head. And so on and on. A closer scrutiny would surely reveal other strange commentary.

Where are the nonconformists—the eccentrics—today? Is there no longer any room for eccentrics in the world of science? Is our modern science environment too sophisticated, too filled with constraints to tolerate eccentricity? Perhaps so. Yet once in a while you meet a scientist who exhibits traits and modes of action that are refreshingly different. I once knew a horticulturist who tried to revolutionize the potato industry by breeding yellow-fleshed tubers. But the idea never caught on—even through his yellow potatoes were far more nutritious than white ones. Discouragement came and the yellow potato was forgotten.

Then I also knew an engineer whose early associates thought he was a kook. But his ideas did catch on, and he became famous. I found him a most stimulating man to talk to—largely because his conversation never fit any predictable pattern. His name was Charles Kettering.

It seems lamentable that our present science system discourages eccentricity. But nowadays one's bread and butter is assured with conformity—a conformity that admittedly has produced some astounding results in the agricultural sciences. Perhaps the eccentrics belong only in the pages of history.—W. W. K.

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LIGNIN: An Inviting Storehouse

JOHN C. PEW

LIGNIN is one of the world's biggest puzzles. It is the second most abundant naturally recurring material on earth, but we are still not sure of its structure. Although we have been able to exploit lignin only to a limited extent, it promises treasures if we can unlock the storehouse door.

Lignin is a major constituent of most land plants; its presence is a key difference between land and aquatic species. It appears in trees and shrubs as well as in mosses, grasses, ferns, bamboos, fruits, and vegetables. It turns up in plant roots, stems, leaves, bark, husks, shells, and seeds. With this widespread distribution, the annual production of lignin is tremendous. Only structural carbohydrates are more plentiful among the naturally recurring materials.

In trees, lignin is present everywhere except in the pith and cambium, along with a few neighboring cells. In the xylem, the content is approximately 20 to 30 percent of the dry wood substance, depending on the species.

A key function of lignin is that it provides necessary strength and stiffness to support the plant. It permeates the amorphous regions in the cellulosic complex, conferring the needed strength and rigidity. It also acts as a barrier to many types of microorganisms that could otherwise readily attack the cellulose.

Significance to Wood Properties and Utilization

LUMBER would indeed be a poor structural material but for the factor of lignification. Cellulose may confer considerable tensile strength, but it is the lignin that is responsible for compressive strength and stiffness. Moreover, lignin restricts the swelling and shrinking of the wood. A block of spruce that, in water, swelled only 7 percent in the tangential direction, swelled 29 percent after the lignin was removed and the block soaked. For structural uses, we accept wood the way nature delivers it, with a more or less fixed lignin content for a given species, although possibly this might be varied genetically.

One way we exploit this rigidity is in steam bending of wood. The lignin reinforcement is thermoplastic in the moist state. Therefore, when wet wood is heated, it may be bent; on cooling it regains its rigidity.

The outstanding example of the chemical manipulation of lignin for industrial use is the manufacture of pulp and paper. This is essentially the re-

moval of the bulk of the lignin from wood by depolymerization and solubilization (digestion), and the remainder by degradation and extraction (bleaching). Some 75 million tons of pulp are produced in the world annually, representing about 40 to 50 million tons of lignin. The lignin solutions, along with soluble carbohydrates and their degradation products constitute "waste liquors."

In the sulfite pulping process, waste liquors were formerly dumped into the streams and were a serious pollution problem. With restrictive legislation and technological development, many of these mills have installed, or are installing, recovery systems, while others have been abandoned or converted to the kraft process. If the present trend continues, stream pollution from sulfite mills will cease to be a problem.

From both processes, a small amount of recovered lignin finds its way into the market for a wide variety of specialized application. These include such uses as plastics, adhesives, dispersants for oil well drilling, concrete additives, chelating agents, tanning agents, sulfur chemicals, and vanillin manufacture. These pulping residues appear to be our best source of raw material as we contemplate using the enormous amount of lignin nature produces annually, for here the lignin is automatically collected and partially isolated. A single large southern kraft mill burns as much as 600 tons of lignin a day.

Lignin is also of concern in mechanical pulps; that is, pulps in which the wood is defibrated without removing the lignin. Here, the lignin is an advantage because it adds opacity to newsprint and magazine papers. Conversely, it gives a slightly yellowish color to the fiber and its photosensitivity causes it to yellow still more on exposure to daylight. Special methods have been devised to bleach groundwood pulp without removal of the lignin, but they do not stop the tendency to revert to the yellowish color on light exposure. Moreover, because of the close association between the lignin and carbohydrate constituents, hydration of the cellulose is restricted, resulting in lower bonding strength in the paper. This factor is sometimes partially offset by chemical treatment or limited digestion of the wood before defibration.

If it were not for the perverse nature of lignin, better utilization might be made of the large amounts of sawdust and shavings produced in the woodworking industry and the vast quantities of wood from low-grade trees. Since this material is composed of 70 to 80 percent carbohydrate, an attractive outlet would appear to be to use it as food for cattle. However, because of its lignin content, wood is almost totally resistant to digestion by ruminants. The carbohydrate is readily digestible when the lignin is removed (as in holocellulose) or if the cellulose is hydrolyzed to soluble sugars. At present, such processes are unfeasible or marginal economically, although in Russia wood hydrolysis is carried out commercially on a considerable scale. Eventually this lignin barrier may be overcome in other ways. Termites and other wood-eating insects have solved the problem for themselves.

Although lignification protects wood against a wide variety of cellulolytic organisms as well as potent isolated cellulolytic enzymes, two types of fungi are able to overcome this shielding action. White rot fungi do it by metabolizing the lignin, and brown rotters apparently break down the tridimensional lignin network by depolymerization, and perhaps by breaking lignin-carbohydrate chemical bonds without removing the lignin. Slow attack by a variety of organisms in the ground causes radical changes in the structure of the lignin, converting it into the very complex substance—humus, a valuable component of our soils.

Another area of lignin effect is in the weathering of wood, where the process of photochemical degradation is involved. Wood lignin decomposes more rapidly than the cellulosic components. With clear finishes that are relatively transparent to ultraviolet light, the degradation proceeds under the film, in time causing cracking or detachment of the protective coating.

When wood is heated to high temperatures, its lignin proves much more stable than the other components. In continued thermal treatment, as in the wood distillation process, a substantial amount of the lignin remains as part of the charcoal. The aromatic compounds in the wood tar are largely derived from the lignin component.

Chemical Structure

RECOGNITION of lignin in wood as a separate entity goes back about a century and a quarter. Although many properties, methods of isolation, and chemical reactions of lignin were examined over the

years, progress in the elucidation of its structure has been painfully slow. There are several reasons for this:

1. Lignin is an amorphous high polymer with a molecular weight of 10,000 or more, even in somewhat degraded material.
2. It is very complex—much more so, for example, than the cellulose polymer it accompanies.
3. Remarkably stable in some ways, lignin has a high chemical sensitivity when subjected to laboratory procedures. A sample of fossil spruce 2 million years old still gave the well-known phloroglucinol color reaction to a discernable extent—even though the coniferylaldehyde groups responsible constitute only 2 to 3 percent of the original structure. Nevertheless, simple boiling of wood in water is believed to cause appreciable hydrolysis and condensation of the lignin.
4. It is safe to say that completely unchanged lignin has never been isolated from wood. In recent years, however, the technique of vibratory grinding, followed by extraction or removal of carbohydrate by digestion in cellulolytic enzymes, has produced lignins with minimal alteration.

Although early workers suspected the aromatic character of lignin, this was denied even in comparatively recent years. The substantial yields of vanillin obtained by Freudenberg in the alkline nitrobenzene oxidation of lignin, the acidolysis to "Hibbert's ketones," the hydrogenation studies of Harris, and the ultraviolet absorption studies of wood sections by Lange—all this research convinced chemists that lignin is essentially a polymer of oxyphenylpropane units (fig. 1).

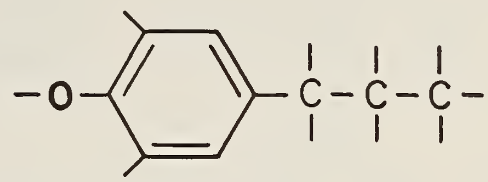
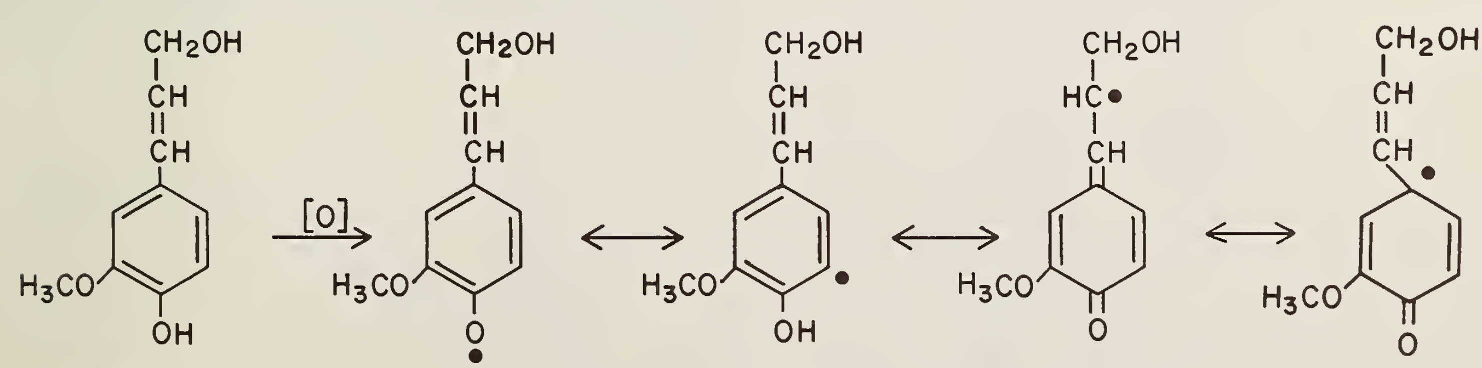


FIGURE 1.—Lignin—a polymer of oxyphenylpropane units.

At the turn of the century, Klason suggested that lignin is a polymer of coniferyl alcohol originating from the glucoside, coniferin, known to be present in the cambial sap of conifers. In the 1930's Erdtman, while studying the dehydrogenation of certain related phenolic compounds, proposed that lignin was a polymer produced in a similar fashion. It remained for Freudenberg, in 1943, to put these ideas together. He and his coworkers have pursued this concept with outstanding success. They were able to form a synthetic lignin by the enzymatic dehydrogenation of coniferyl alcohol and by arresting the process in the initial stages to show that dimers and larger units are formed intermediately as predicted by a free radical pairing mechanism. More than 40 of these "lignols" have been identified, including even a hexamer. The mechanism, in simplified form, is illustrated in Figure 2.



I (a) (b) (c) (d)

CONIFERYL ALCOHOL

FIGURE 2.—Free radical forms from coniferyl alcohol.

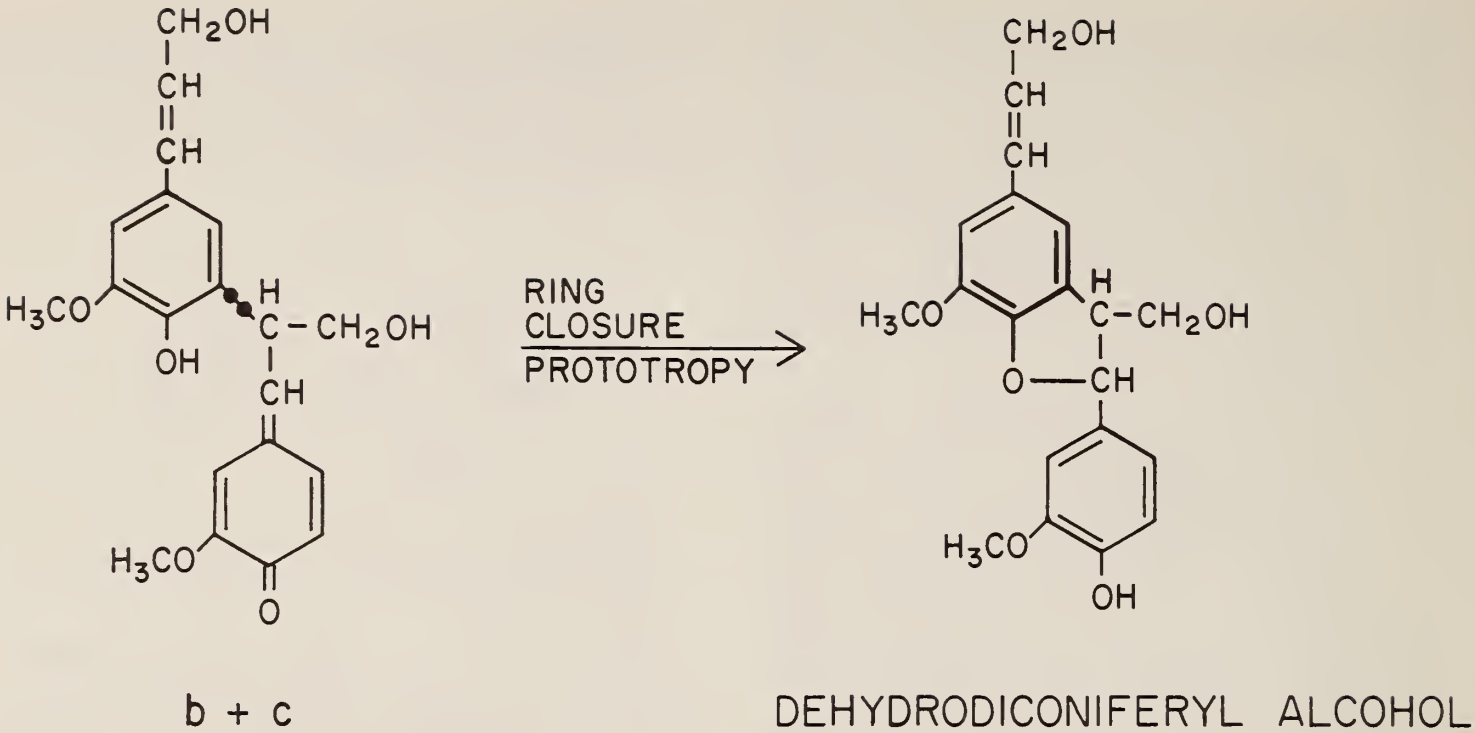


FIGURE 3.—Example of free radical pairing during lignification.

Coniferyl alcohol (I) is oxidized to the phenoxy radical (a) in which the unpaired electron is indicated by a dot. This, with its mesomeric forms (b) and (c), becomes neutralized by pairing, resulting in dimers containing one or two unstable nonaromatic rings with a quinone methide structure. In the dehydrodiconiferyl alcohol illustrated (b+c) this becomes stablilized with return to an aromatic structure by ring closure (fig. 3). Similar pairing takes place to form pinoresinol (c+c) (fig. 4).

After pairing of (a) and (c), ring closure is not possible and water may add to form guaiacylglycerol-β-coniferyl ether (fig. 5). This is an important point in lignin structure, since Harkin has shown that this quinone methide reacts with other hydroxyl-containing compounds such as alcohols, phenols, and sugars. This provides, therefore, a second means by which the lignin polymer is built up, one which does not involve a free radical mechanism. The reaction with sugars is also very significant, since it could occur with wood polyoses and probably is the basis of a lignin-carbohydrate bond in wood.

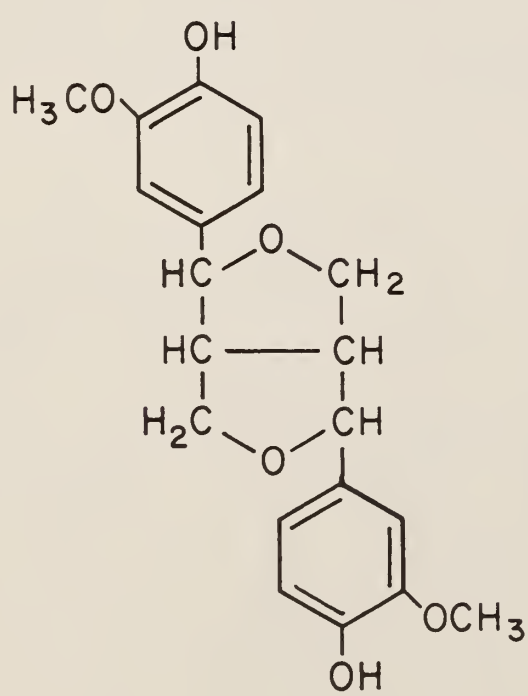


FIGURE 4.—Pinoresinol.

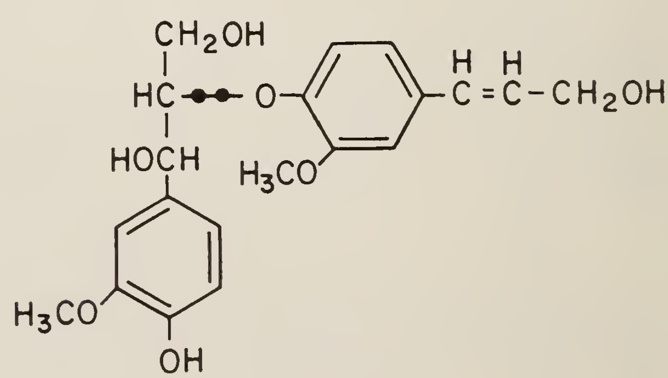


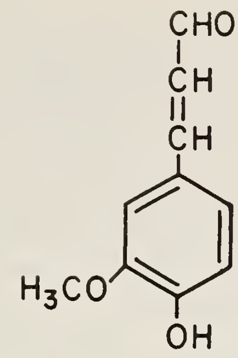
FIGURE 5.—Guaiacylglycerol-β-coniferyl ether.

The above secondary dimeric products were actually isolated by Freudenberg; and evidence of the pair (b+b) to form a biphenyl compound and the pair (a+b) to form a diphenyl ether was indicated by degradation of the dehydrogenation product and of lignin.

The participation of radical (d) has only recently been discovered. Lundquist and Nimz, working independently, have found compounds without 3-carbon side chains in products of mild lignin degradation. It is postulated that, after pairing, the alicyclic ring reverts to the aromatic state by expulsion of its side chain. In the dehydrogenation of phenols with substitution unrelated to lignin, this type of radical is know to pair, retaining its alicyclic dienone (or with ring closure, enone) structure. Our own experiments with the dehydrogenation of lignin model compounds have suggested that both types of reaction occur and that the participation of this radical is by no means minor.

Thus it appears that the linking of coniferyl alcohol units is quite involved. The actual situation in lignin is still more complex. It is known that various lignins contain, in addition to the guaiacyl ring as in coniferyl alcohol (I), the corresponding dimethoxylated group (especially in hardwoods) and nonmethoxylated group (especially in annual plants). These, presumably, are introduced by copolymerization as the corresponding *p*-hydroxycinnamyl alcohols II and III (fig. 6).

Compound II cannot form a radical in the *ortho*-position while III has two *ortho* pairing positions. A further complication is that a little of the



IV

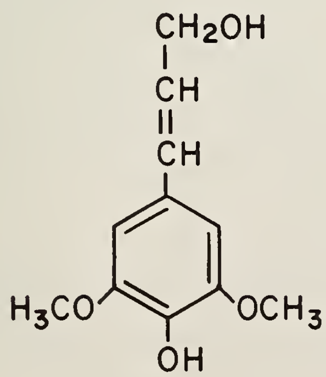
FIGURE 7.—Coniferaldehyde structure (IV).

p-hydroxycinnamyl alcohols becomes oxidized to the corresponding *p*-hydroxycinnamyl aldehydes and acids, either before or after pairing.

Units with the coniferaldehyde structure (IV) (fig. 7) are the cause of the long-known purple-red color given by liquified tissue with phloroglucinol and hydrochloric acid. With the *p*-hydroxycinnamic acids, the terminal carboxyl group (COOH) participates in ring-closing reactions.

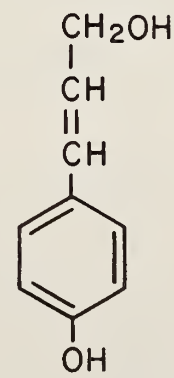
In the above, only the initial pairing reactions were discussed. The resulting dimers have a free phenolic hydroxyl group capable of dehydrogenation. In some of the dimers the β-carbon atom is not conjugated so that radical type (c) is no longer possible, but types (a), (b), and (d) can be formed.

Since the various kinds of groups and linkages described can occur in a variety of sequences, the detailed structure of lignin must be extraordinarily



II

SINAPYL ALCOHOL



III

p-HYDROXYCINNAMYL ALCOHOL

FIGURE 6.—*p*-Hydroxycinnamyl alcohols II and III.

complex. Although the above concepts are based on indirect evidence, degradation studies of lignin by Freudenberg, extensive chemical reaction studies by Adler, the isolation and identification of small fragments by Adler, Harkin, and Nimz, and the work of many others—all have generally supported the synthetic experiments.

Biosynthesis of Lignin Precursors

According to Freudenberg, the *p*-hydroxycinnamyl alcohols which serve as progenitors for lignin formation may be derived from the corresponding glucosides present in the cambial sap and transported from other parts of the tree. Others have suggested that their formation takes place mainly within the cell that is being lignified, the glucosides in the sap being present as a reserve material. The biosynthesis of these alcohols from carbon dioxide has been studied by means of radioactive tracers by Brown and Neish (1955) and by other workers, but can be only briefly mentioned here. A likely sequence is illustrated in Figure 8.

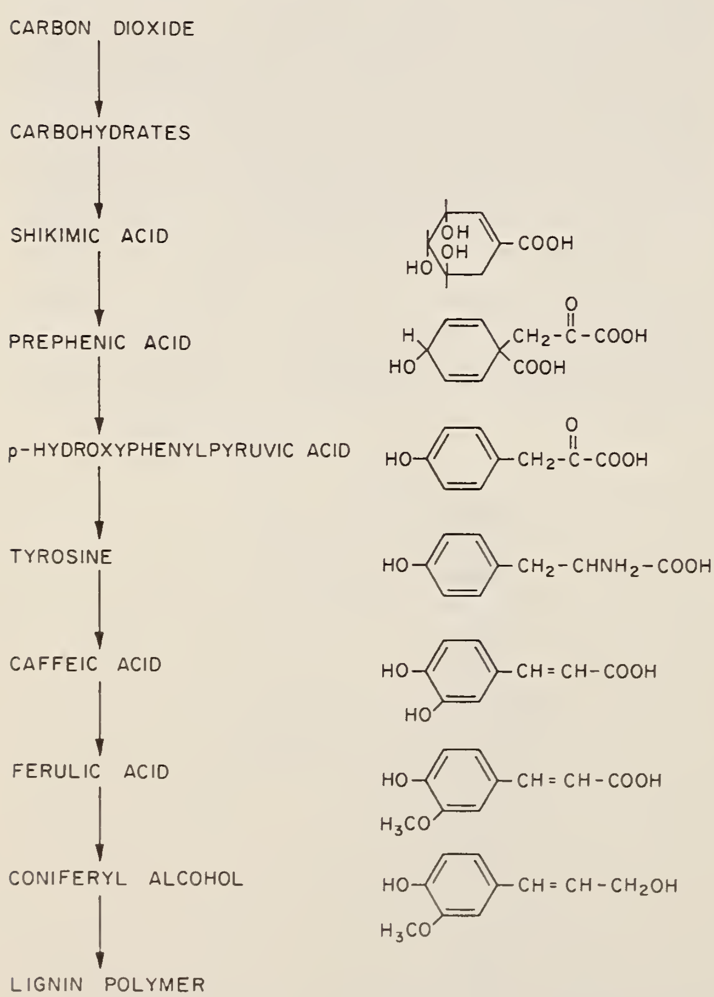


Figure 8.—A likely sequence in the biosynthesis of *p*-hydroxycinnamyl alcohols from CO_2.

Association of Lignin with Carbohydrate Constituents

An important problem in lignin chemistry, especially from a technological standpoint, is the nature of association between the lignin and carbohydrate components in wood and other plants. This has been debated almost since lignin was recognized as a unique entity. One school of thought maintains an "incrustation" theory; the second insists on chemical bonding. It now appears that the situation is not this simple.

The probability of an ether-type chemical bond resulting from the reaction of quinone methides with hydroxyls of the carbohydrate constituents has been mentioned above. Glycosidic bonds with phenolic hydroxyls in the lignin also seem logical, and some evidence has been presented for their occurrence. The presence of an acetal bond between carbonyl groups in the lignin and carbohydrates has recently been postulated. But in addition to chemical bonding, the surrounding of amorphous carbohydrate chains by the three-dimensional lignin network must also make a very important contribution to the properties of wood. Analogous combinations of this sort have been prepared in the synthetic polymer field. Finally, the large number of hydroxyl and ether groups in lignin, and hydroxyl and acetal groups in the carbohydrate, indicate the likelihood of substantial hydrogen bonding between the two components. The actual demonstration of these types of bonding in the wood is a very difficult task.

Future Work

In future work on lignin we should not allow the great complexity of the substance to discourage us from delving further into its chemical nature. Probably a complete, detailed elucidation is beyond our present powers; but the ever expanding methods for probing into organic structures may come to our rescue.

In the meantime, much more could be learned about the predominating structures and sequences. One approach is the search for new degradative methods aimed at splitting lignin into small fragments without concurrent repolymerization or irreversible addition of foreign groups. Many of our current ideas of lignin structure are based on monomeric cleavage products but these may represent "fringe" groups rather than the "core."

Further knowledge of the constitution of lignin and its chemical reactions should enable us to improve our technological processes and permit us to design methods of utilization. Even a complete knowledge of structure would not automatically lead to better use, but it would provide a foundation on which to build more logical applied research. Indeed, the opinion has been expressed that enough of the chemistry and structure are now known to provide a new approach to the lignin problem. The newer concepts of structure are already being applied to improve our understanding of the mechanism of chemical pulping. No doubt this will eventually be reflected in the actual industrial processes.

In most of our efforts to modify wood for various purposes, the modification has been aimed at the major component, the carbohydrate. Perhaps we should direct more of our efforts toward the lignin fraction. We mentioned that lignin protects wood against a variety of cellulolytic organisms but fails with brown and white rots. If the lignin could be chemically altered to resist even these fungi, the whole structure would be protected. Similarly, if the photosensitivity of lignin could be diminished by suitable treatment, then bleached mechanical pulps would retain their whiteness better; furthermore, the weathering properties of exposed wood could be improved. An example of chemical modification of lignin is in the recent experiments of Lewin, who found that the introduction of bromine into wood gave good fire-retardant properties. It is difficult to combine bromine with carbohydrate, but the well-known reactivity of bromine with lignin provided a convenient means of attachment.

The modification of the lignin might also be aimed in the opposite direction. Since lignification is the principal factor preventing digestion of wood by ruminants, possibly the lignin barrier could be broken down by depolymerization or degradation without the expense of removing it from the structure. Vibratory grinding of wood permits as much as 96 percent of the carbohydrate to be digested by cellulolytic enzymes. Even the preswelling of wood in alkali allows substantial digestion to take place. Perhaps an economical partial depolymerization scheme could be developed.

Many ideas and experiments in the past involving lignin have so far not been successfully worked out. New knowledge of lignin chemistry, new solvents and other chemicals, new engineering methods and materials might put these in the realm of practicability. For example, the possibility of using organic solvents for pulping, recovering the solvent by distillation, and leaving a residue of lignin is conceivable.

A novel pulping idea has recently been explored in California: using the pulping action of nitric acid on wood but improving the economy of the process by adding the spent liquors to irrigation water, thus utilizing the nitrogen content as a fertilizer.

Isolated papermill lignins are being converted to useful plastics by suitable additives and chemical treatment. Could such a process be carried out *in situ,* thus furnishing a self-binder for the variety of chip and fiberboards now on the market?

The industrial hydrolysis of wood with acids is successfully carried out in Russia. Lignin in solid form separates as a byproduct and considerable research is being directed at its utilization. Any major improvement in the economics of the process might start the industry here and provide a new source of lignin for possible exploitation.

Finally, the conversion of lignin to chemicals must not be overlooked. For general chemical production, the substance cannot, of course, compete with petroleum; but for specialized chemicals there may be a prospect. All of the vanillin now produced in the United States is made from sulfite-spent liquors. A variety of organic sulfur compounds are being manufactured from pulping spent liquors by utilizing the methoxyl group of the lignin and the sulfur of the pulping liquors.

Without depending on miracles from lignin, we can expect an expansion in the use of this abundant natural material.

SELECTED REFERENCES

Several workers have been mentioned in the text, but individual references are not given. The literature on lignin, though extensive, is well documented and several good reviews have been written.

For a history, early work, long-known chemical reactions, methods of isolation, methods of estimation, and references to papers up to 1959:

Brauns, F. E.
1952. The Chemistry of Lignin. Acad. Press, N.Y.

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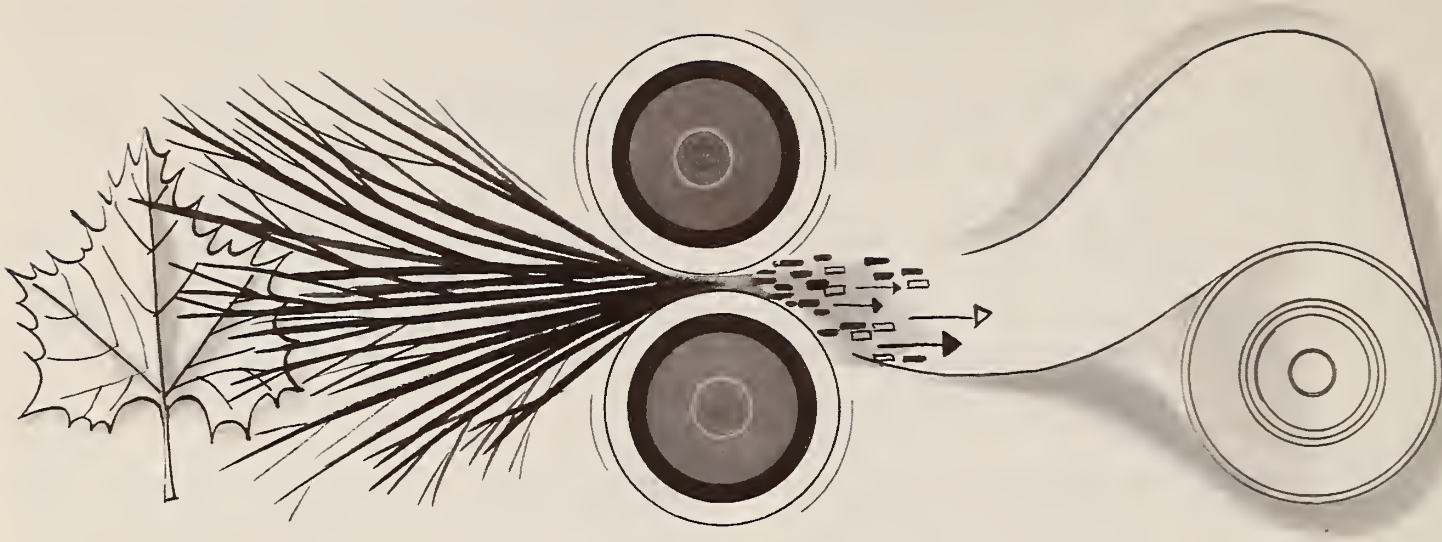

A New Concept in Cellulose Production
SILAGE SYCAMORE

ALLYN M. HERRICK AND CLAUD L. BROWN

IT is often said that good ideas are where you find them. In the world of science, conceptualization may occur in various and often strange ways—from logical rationalization following a series of methodical experiments . . . to the pure serendipitous discovery . . . or to the new concept that comes from brainstorming or "way-out" thinking of a small homogenous group of scientists.

The new concept discussed in this paper falls in the latter group, and the authors want to document the process here because it represents one that might be used more frequently and advantageously by researchers who face seemingly unsurmountable problems.

The setting was the Eighth Southern Forest Tree Improvement Conference held in Savannah, Ga. during mid-June, 1965. This meeting, like previous ones, was notable for the excellent papers presented, the variety of projects reported, and the dedication of the scientists participating. One could sense the tone of progress and accomplishment in the upgrading of forest trees for the future well-being of the region's timber economy, and could not help feeling proud to be a witness to such advancement.

After the close of the meeting, optional field trips to several research installations were available to those who were interested. One trip was planned to the ARS Plant Introduction Station near Savannah, where bamboo, kenaf and other species are being studied as possible sources of fiber for pulp. But that afternoon it began to rain. The prospect of a field trip looked less attractive. So instead, four of us—a tree physiologist, a silviculturist, and two administrators of forestry research—repaired to a hotel room for relaxation and reflection.

Consensus was that the geneticists and tree breeders were doing a bangup job. Yet, early in the discussion the question was broached: "When will progeny-tested, genetically-superior pine growing stock be available on an industry-wide basis?" The estimates ranged from 20 to 30 years. Remembering the reasons behind a comprehensive study of forest taxation then underway in Georgia, and recalling the increasing shortages of woods labor, we began

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to wonder whether the valiant efforts of tree improvement researchers would pay off. We wondered if even a doubling or tripling of the growth rate would shorten rotations to a point where timber growing could proceed on a sounder financial basis.

Assuming we could produce the crop of pulpwood on a 10- or 12-year rotation, how would we get it from the stump to the mill in the face of critical shortages of woods labor? Even acknowledging the striking advances already made in mechanizing the harvesting operations, we wondered whether these developments—or those yet to come—would solve the problem in forestry known as "logging the mill." Further relaxation engendered still further brainstorming. We reflected on the current tax and labor situation as they are affecting forest industries.

Taxes and Tight Labor

AN increase in *ad valorem* taxes on forest land is apparent—at least in Georgia—as a result of revaluation programs necessary to raise additional revenue for operating local governments. Unlike other crops, timber is considered realty in Georgia. Moreover, assessors sometimes are influenced by sales at very high prices of forested tracts for vacation cottages, recreational uses, or various types of speculative investments. The law supposedly requires that assessment for tax purposes be based on fair market value. But not all timber land is suitable for second homes or recreational use.

Under existing stumpage price levels and timber production rotations, an annual tax burden in excess of $1.00 per acre can become confiscatory to the point of forcing premature liquidation of growing stock. However, even if the rapid increases in forest land taxes are arrested, growers still must shorten rotations significantly in order to produce chips for fiber or reconstituted wood products at a profit. Greater volume production on intensively managed land and fully mechanized harvesting operations will be required. If the concept of fiber production were to change drastically from the cutting of individual pine pulpwood sticks and loading and transporting them to the mill for debarking and chipping, mechanical monsters for site preparation and harvesting might not be required. Instead, foresters would commence growing wood on very short rotations where high-speed cultivators and converters would be called for.

The Unanswered Questions

MEANWHILE, back at the hotel room, our thoughts began to synthesize. Was there really a significant difference between kenaf as a short-rotation crop and some tree species? Was there a tree of wide geographic range and adapted to a variety of sites that would coppice readily and vigorously? One that was relatively free from insect and disease attack, that had thin bark and yet some pulping possibilities, and, moreover, a species with which we had had some silvicultural research experience? We decided that the familiar American sycamore was "it."

The dreaming went on. We would grow our sycamore crop on good land with close spacings and produce at least 40 times the tonnage possible with cotton. We would use aerial applications of fertilizers and pesticides and defoliate before harvest, if required. We would use a machine like a silage chopper to harvest our crop, cutting the stems with an oversized sicklebar 3 or 4 inches above the ground to provide an adequate stump for sprouting. The entire tree would go through a chipper mounted on the harvester and the chips would go directly into a trailer hitched on behind. The trailer when full would be drawn to a roadside, where the chips would be transloaded for hauling to the mill or a pipeline terminal.

Next questions! What were the pulping characteristics and qualities of juvenile sycamore? Would it be possible to use the entire tree—bark, twigs, and leaves—to avoid costly debarking and separation of "trash" from the woody fibers? Could this type of raw material be used in large volumes in an adhesive-bonded product? At what spacings and densities should sycamore be planted, and at what intervals should it be coppiced to make optimum use of the stored food in the rootstocks after harvesting a crop? With what kinds of pests would we have to contend under this sort of monoculture? We raised countless questions that only research could answer. So, in a different environment over the ensuing months, we laid plans for a wide variety of studies.

First Research Approaches

DURING 1966–67, the School of Forestry at the University of Georgia—in cooperation with the Forestry Sciences Laboratory of the U.S. Forest

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Service in Athens—established rather extensive, well-designed field studies at five different locations to test the actual performance of several hardwood species under short-term, coppice rotations. The Georgia Forest Research Council and industrial sources are contributing financial support and other forms of backing. Hopefully, these studies will give us, within the next 5 years:

1. Adequate data for predicting yields.
2. Guidelines for optimum site utilization.
3. Points of initiation of genetic improvement.
4. Opportunity to develop suitable harvesting equipment.
5. Information on quality of pulp and paper produced.
6. Possibilities of using intensively-managed young trees for a variety of new forest products.

Although we have just begun to research many of the practical aspects of growing trees at row crop spacings, we do have some actual measurements on yields (green matter per acre) of young sycamore trees growing at 6 x 8 ft. spacings on good sites. This information was obtained through the cooperation of the Southeastern Forest Experiment Station by sampling small plots in plantations previously established as part of a hardwood fertilization study near Athens, Ga. Many of the trees were over 40 feet high at the end of their fifth growing season, and the average weight of their main stems, excluding branches and small limbs, was 45.5 pounds per tree. Based on these sample plots, this plantation of 5-year-old sycamore had produced more than 13 tons of green bole wood per acre per year, or the equivalent of about 5 tons of dry matter—roughly double the average yields of southern pine.[1] If we had utilized all the small branches and twigs from these trees, which we have done in more recent pulping tests, the yields per acre would be considerably higher. Furthermore, if these same trees had been grown at 4 x 4 ft. spacing and coppiced at 2 or 3 years (taking advantage of rapid sprout growth), yields unquestionably would have been even higher.

In some of our small nursery-bed plots where young hardwood trees are grown for propagation, coppice yields have exceeded 25 tons of green matter per acre. We feel reasonably sure, therefore, that sycamore or sweetgum trees growing on good upland agricultural sites at 1 x 4, 2 x 4, and 4 x 4 ft. spacings, coppiced at 2- to 3-year intervals, will yield well in excess of 10 tons of dry matter per acre annually. This figure is approximately five times the dry matter production of abandoned fields (weeds) in the Georgia Piedmont, and about one-half the annual dry matter production of sugar cane (17 tons per acre) in Hawaii.[2]

With intensive silvicultural treatments such as yearly fertilization and possibly cultivation or mowing for weed control, coupled with rapid gains from genetic selections, we foresee the possibility of boosting the annual yields to 20 tons of dry matter per acre. This figure would approach pulpwood yields of approximately 13 cords per acre each year—a 5- to 6-fold increase over current methods of producing woody fiber under silvicultural rotations of 30 to 40 years.

Complete Site Utilization

TODAY most fiber production plantations are established in rows at spacings ranging from 6 x 6 to 8 x 12 feet. Some spacings may be up to 15 x 15 feet for specific purposes such as the production of gum naval stores where large, well-developed crowns are essential for high gum yields. Currently, wide spacings such as 8 x 10 or 8 x 12 feet are preferable to closer ones because the trees can reach merchantable size by the time the first thinning is needed. Otherwise, under the present size limitations placed on pine pulpwood (3 inches at the small end of a bolt), thinnings in young, closely-spaced stands would be an out-of-pocket cost, because the products removed would have no commerical value. In many European countries the initial tree spacings are somewhat closer than those used in America, because there is usually some demand for small trees for fuelwood or other products.

Spacings of 1 x 4, 2 x 4, or 4 x 4 feet may likely be the vogue within the next decade. For the many reasons mentioned earlier, complete site utilization for fiber production is an economic necessity. Management can ill afford to wait 15 or 20 years for the first harvest where only part of the land is utilized as growing space. During this period of juvenile tree growth, crowns and roots are spread-

[1] "Silage Sycamore", R. G. McAlpine, C. L. Brown, A. M. Herrick, and H. E. Ruark, *Forest Farmer*, 26:6–7, Oct. 1966.

[2] "Fundamentals of Ecology", E. P. Odum, 2nd Ed., W. B. Saunders Co., Philadelphia, Pa., 1959, pp. 71–79.

FIGURE 1.—One-year-old sprouts of sycamore from 2-year-old stumps at a 1 x 3 ft. spacing.

ing outward, forming a mass of organic material unsuited for pulp and paper production. With initial close spacings such as those used in agronomic crops, all available growing space can be immediately utilized.

Pounds-per-acre cellulose yields on a given site can be increased tremendously by taking advantage of this basic principle. That is, instead of utilizing the sun's energy for crown and root production for years on end, this energy can just as easily be used to produce cellulose on myriads of small stems per acre. Many hardwood trees are exceptionally well adapted for a system of "silage cellulose" because, being perennials, they possess the remarkable ability of sprouting profusely from the root stocks. Once a crop is planted at row-crop spacings and harvested at a very early age, say at 2 or 3 years, the next crop is automatically assured without replanting. Only fertilization will be required to keep the level of productivity high. We need only to determine what combination of spacings and harvesting ages will give the greatest sustained yields of cellulose per acre. Several experiments with different hardwood species on various sites are now in progress (fig. 1).

The primary biological principle underlying short-term coppice rotations lies in the fact that photosynthetic materials may be recycled at appropriate intervals from the root systems of young, severed tree stems in the form of luxuriant sprout growth during the following season. Ordinarily, most of this material would have been lost forever in terms of fiber for the paper mills. In accord with all biological principles, there is an upper limit to energy conversion and recycling into fiber at the expense of root development, but we think the proper balance for maintaining high yields can be ascertained in a relatively short period.

Genetic Improvement

UPPER levels of productivity are not reached by intensive cultural practices alone. The genetic or biological potential of the crop trees must also be raised sharply. This we know can be done. Take the well known example of hybrid corn—a story unparalleled in man's history of what can be achieved in breeding and selecting for increased yields. The same techniques and principles apply to forest trees. The concept of short-term coppice rotations further enhances the progress already made in forest tree improvement. By reducing the rotation age of fiber production to a maximum of five years, progeny testing of woody plants for photosynthetic efficiency in terms of pounds of cellulose per acre will take on added meaning.

Progeny testing to the end of a 25- or 30-year rotation for pulp yields in the Southern pines is now deemed essential by many forest geneticists before selecting and breeding for the next improved crop of trees. This long-term aspect of tree improvement can be entirely circumvented in coppice hardwood rotations. In fact, the entire approach to genetic improvement can be initially geared to selection among millions of genetically heterozygous seedlings of local seed source planted at a given site. Here, indiv-

dual selections for actual coppicing ability can be made when the trees are 2 or 3 years old, and their genetic worth can soon be determined in a program of breeding and selection. The costly procedure of establishing acres of grafted seed orchards can be completely bypassed, because selected clones can be produced in quantity by mass propagation of cuttings as is now done with horticultural strains of ornamental plants or fruit and nut trees. At the same time, a program of recurrent selection, or even hybridization, could be adopted to supply genetically improved seed for the next seedling generation of crop plants. By the end of the second field-harvesting cycle (3 to 5 years later), a new clonal variety with even greater biological potential could be ready for release. Therefore, shortening the time of rotations to an almost unbelievable 3, 4, or 5 years for woody fibers opens up new vistas for the forest geneticist and puts practical forest tree improvement into the main stream of a fast and highly competitive economy.

In our opinion, the forest industries cannot afford to progeny test trees for as long as 30 years before deciding what ones to select for future breeding. By the time a given strain with certain wood properties is produced under such a scheme, advances in chemical engineering and polymer chemistry may likely render the product uncompetitive. Conversely, there will always be a demand for raw cellulose. And the seemingly logical way to mass produce it is with closely spaced trees under short-term rotations, where more rapid genetic gains can be made than are possible under the current tree improvement programs.

Efficient Harvesting Procedures

THE archaic methods now used for pulpwood production can exist only for a few more years at most. Automation will come by necessity and the use of short-term coppice rotations clearly makes such automation possible. In trial runs with a lightweight corn silage harvester, one-year-old sycamore trees were effectively harvested and chipped as shown in Figure 2. For actual field harvesting on a commercial basis, heavier equipment operating on the same principle would be required. Mowing several acres of young hardwood trees and chipping them into small pieces in the field would certainly be an improvement over the power saw and hand-loaded pulpwood truck of today. The reduction in labor cost alone—to say nothing of alleviating all the problems that go with recruiting and maintaining woods labor—would be a panacea to the pulpwood producer.

Of equal consideration in shifting to an automated, short-term rotation are the possibilities offered in the contract production of fiber. Many farmers would be anxious to further diversify their operations by growing trees on a contract basis similar to peanuts, tobacco, or poultry. By supplying the land and such practices as cultivation and fertilization of the crop trees, the fiber industries

FIGURE 2.—Trial harvesting of young sycamore sprouts with a conventional silage harvester.

could harvest the crop when needed, pay for the fiber removed on a per-acre or weight basis, and return for a second harvest within a 2 or 3 year period. This would alleviate long-term capital investments in land and improvements, and "log the mill" with increased facility. The returns to farmers and producers of paper or other cellulose products should be mutually advantageous.

Quality of Paper and Other Products

AT first thought, the layman—and indeed some foresters—might question the possibility of using 3- to 5-year-old trees for fiber. Some of the immediate objections might be: How do you propose to remove the bark from such young trees? And isn't it true that juvenile wood does not possess the strength properties of older trees?

Actually, bark removal is no problem; it is simply chipped and used along with the wood in young, thin-barked hardwood species. In unbleached sulfate pulp, the few bark flecks present are no problem. As a matter of fact, in experimental trials where entire young sycamore trees (bark, leaves, twigs, and wood) were chipped and cooked together, the process produced an excellent quality of paper that could be used for a variety of purposes.[3]

Cooking time was considerably less for pulp from these young trees than for that from Southern pine or older hardwoods—indicating a substantial reduction in processing costs, a notable attribute at any paper mill. It is true that the strength properties of juvenile wood, and especially its specific gravity, are considerably less than those of older, more mature trees. But they are not so low as to seriously affect its use. In fact, many mills prefer to blend hardwood fibers with conifer fibers for certain paper or container products. Therefore, fiber from young hardwood trees processed with less cooking time could be used advantageously for a wide array of products.

Current tests of 5-year-old sycamore trees in the manufacture of particle board and other bonded materials indicate that the species is equally well-adapted for such uses. The extent to which young hardwood trees can be utilized for construction materials in housing and commercial building is limited only by our failure to recognize the possibilities to which wood, in some premolded form, can be put to work. It seems likely that with automation in woodlands production and harvesting, a wide variety of newly created wood products will reach consumer markets. For example, low-cost, prefabricated, highly versatile, wood-plastic housing offers one promising outlet for those willing to exercise some imagination in the use of partially processed wood. Likewise, hundreds of new products using wood fibers or cellulose as a base could be produced from young trees regenerated by coppice on limited areas of land.

Summary

IT seems inevitable that new concepts and approaches must be sought to assure an economically sound future in the processing and utilization of forest products. The spiraling costs of labor, the ever-increasing taxes, expanding urbanization, and other associated trends in our socio-economic structure—all these point to a necessity for rapid conversion to complete automation of woodland operations. The day of the power saw, skidder, and pulpwood truck is doomed; the industry can ill afford to handle bolts of pulpwood by manual labor much longer.

At this stage in our research, a number of distinct advantages associated with short-term, coppice rotations seem apparent:

- Reduced capital investment and improved tax benefits.
- Woodlands automation from planting to the mill.
- Increased yields through intensive land management.
- Genetic gains in the shortest time possible based on yields of cellulose.
- Contract production of fiber on private lands.
- More uniform physical properties of wood.
- Programmed harvesting at any season.
- Reduced conversion and utilization costs.
- Production of a renewable raw material economically competitive with synthetics.

Hopefully, therefore, this new concept in the production of cellulose will enhance the future of forestry the world over.

[3] Report on Project No. 540–S of the Herty Foundation, Savannah, Ga., dated November 18, 1965, to the Georgia Forest Research Council (Project JB–826).

Why Don't Students See Orion?

EDWIN L. PETERSON

PROFESSOR EDWIN L. PETERSON, one of the best known and most celebrated teachers of creative writing in the country, has retired after forty fruitful and rewarding years of service on the faculty of the University of Pittsburgh.

The editors of Pitt, *quarterly alumni publication of the University, felt that this event should not go unremarked in the pages of their journal. For here was a man who has created his own best testimonial through both the writers and writing he has turned out.*

So, instead of doing the usual thing—a recounting of his many accomplishments and contributions—the editors of Pitt *asked Peterson to "roll a blank sheet of paper in his typewriter and put down whatever random thoughts came to him, reflecting on almost a half century of helping young men and women express their thoughts."*

The result is a series of notions that contain something of the essence of a great teacher. Since a large segment of our readers includes both teachers and students at the university level, the staff of REVIEW *is privileged to share some of Professor Peterson's "notions." We suspect that even bench scientists—far removed from the classroom—may well glean something to help them "see Orion."*

Notion No. 1

OFTEN I am shocked to realize that many of my students never see the heavens. They live in cities or in heavily populated suburbs, and the street lights blind them to the stars. Mention Orion to most students, and they look at you in bewilderment. They have read about the Great Dipper, some of them, but they have never lain on the top of a hill and watched the constellation move about the North Star. Strange world that wants to put a man on the moon but that cannot look at the stars!

Notion No. 2

EVEN after 40 years I am still puzzled by the advice given to entering freshmen who have good high school records in writing. At almost every university the advice is the same: "According to your grades, Mr. Freshman, you must write very well. You don't need any more work in composition. We'll put you in a literature class instead." But if the student has a good record in physics, the adviser says: "According to your grades, Mr. Freshman, you're very talented in physics. You should go further in this field. You should probably major in it." So the advice would go if the student were talented in chemistry or French or mathematics. But in English composition, the advice is, "You're good at writing, so quit it." I wonder why. I have been wondering why a long time.

All high school students could write better, even the best. All college English teachers could write better, including this one. Some college English teachers, I must admit, write very poorly indeed. Perhaps they, too, got the wrong advice when they were freshmen. It is even possible that some of them should be taking English 1 and 2 for the first time instead of teaching it.

Gladys Schmitt, one of our great American novelists, took English 1 and 2 and would be the first to say that the courses had value. A few years ago, Peter Beagle took English 1 and 2 and did not complain and yet he was good enough to write almost all of his fine first novel before he finished at Pitt. Why, when students are good at writing, are they told to take no more writing?

Notion No. 3

IN measuring the student as a whole, grades seem less important than educators say they are. I am always a little suspicious of the straight A student. I am also a little suspicious of the straight A student in English or fine arts who cannot catch a baseball and who is contemptuous of the boy who has muscle and courage enough to be on the wrestling team. A Phi Beta Kappa who says, "Who's he?" when someone mentions Roberto Clemente is not, I suspect, a whole man. Grades do not measure integrity, endurance, manual dexterity, graciousness, truthfulness, or a profound attitude towards man's duty in a confusing world. Some C students have these human and honorable virtues in greater abundance than the honor student. And some honor students admit that they got that way by frequent glances at a neighboring student's paper.

There is much to be said for the C student. In many instances he is vastly underrated as a human being. And the B student is often a better bet to give something important to humanity than the A student. At Harvard, F.D.R. was not a Phi Beta Kappa, and Ernest Hemingway never was graduated from college. For that matter, neither was Tennyson nor Rosetti nor Browning nor Swinburne—though college students study their writing. It was Oscar Wilde who was graduated with honors.

Notion No. 4

WHY do college literature teachers so seldom write literature? The good chemistry professor, I am told, tries creatively to add something to chemistry, the physics teacher to physics. Could it be that the science teacher tries harder to be creative than the English teacher? I hope not, but after 40 years I find that strange thoughts tumble around in my mind. That could also be a sign of senility. I'll drop the subject.

Notion No. 5

EVERY college in America should have a course called Quietness 1 and Quietness 2. It would meet for one hour on Mondays, Wednesdays, and Fridays. The classroom would be a tiny cubicle, large enough for only one student, and either dimly lighted or completely dark. The student would not be permitted to take books or paper or pencil with him. For the full period he would sit there and do a little thinking. There would be nothing to distract him. He would be alone with himself and the things he had learned and might come to realize the relation of each to the other. It would not be so good a class as the one Izaak Walton described when he wrote, "We sit on cowslip banks, hear the birds sing, and possess ourselves in quietness," but if the student came even close to possessing himself in quietness, the class could be the most important one offered by the university. Come to think of it, Quietness 1 and 2 should be an *eight* semester course.

Notion No. 6

I SHOULD not want a son or daughter of mine to rush through 4 years of college study in 3 years. Part of education, a vital part, involves reflection. A student must have time to think things over. It is easy to read Faulkner's, "I believe that man will

not merely endure; he will prevail." One can do that in a second. But mere reading is not enough. The serious student wants time to think about Faulkner's statement, to weigh it, to evaluate it, to turn it over and over again in his mind until, if he accepts the statement as sound, it will become part of his life and character. To do so may take hours of reflection and aloneness. It may take weeks. It may take a whole summer of deep, if intermittent, contemplation. If the student, instead, merely rushes from one class to another and from one school session to another, he is not likely to be affected by Faulkner's idea. It is easy to read, "I am a part of all that I have met." It is less easy to absorb the idea and to become part of it. Anyone can understand the superficial meaning of "And never lifted up a single stone," or "Cover her face, mine eyes dazzle, she died young," or "Sings hymns at heaven's gate." But to enter into their fullness and richness may take many solitary hours on a hilltop or many lonely walks on empty streets. College years are years for absorbing more than facts. They are the years for growing into wisdom, years when at least a few months every summer are spent not in study as such but in becoming part of all that they have met in college and out of college.

Notion No. 7

ONCE in a long while I have helped a student. Maybe I have taught him to write a better sentence or to recognize the difference between *effect* and *affect* or to look with greater accuracy at the ginkgo trees on the campus or to realize that his mother and father have problems just as he has or to refrain from making generalizations unless he can support them with evidence. Sometimes the student says thank you at the end of the semester or a couple of years later in a letter or a Christmas card. Once in a while he brings his girl to the office to show her off with pride. On rare occasions he visits his teacher long after graduation—as Bill and Helen and Mary do even now. These are big rewards. They help to make life worth living. They help to restore whatever faith the teacher may have lost in people. Teaching is a good job.

Notion No. 8

IN my day as a student we "took" teachers, not courses. Today, I think, the student takes courses regardless of the teacher. The student may be right in doing so. Perhaps the content of the course is more important than the teacher's attitude towards it and towards other things. And yet I wonder. It seems to me that I remember very little information that my courses gave me. Today I should find it difficult to translate a Latin paragraph, a Greek poem or even, I fear, a passage from *Beowulf*. I could not prove a geometrical theorem, nor could I quote accurately the second law of thermo-dynamics. Yet I remember clearly my extra curricular teacher of Greek, the world weariness of my Old English teacher, the geometry teacher who stared out the window one morning and said, "Geometry is so right it's a little like God," and the chastening fear that entered my mind when my physics teacher explained the philosophical implications of the second law of thermo-dynamics implications that altered many of my traditional religious concepts. Few teachers would have dared to interpret the fact or theorem as he did, and I am eternally grateful to him for doing so. Most of my courses and their content I have almost forgotten, but the few great personalities I knew as teachers I shall know always. I have a feeling that today students, especially undergraduates, take courses rather than teachers. I hope I am wrong.

Notion No. 9

THE information presented in a course has little value unless it is so taught that it stirs up something in the student himself. "Music," said Walt Whitman, "is that which arises in me when I am reminded by the instuments." Great education and great teachers furnish many reminders.

Notion No. 10

IN an institution as large as the university there are many complainers. There should be. I have done my own share of complaining, as department heads, deans, vice-chancellors, and even chancellors could attest. Usually the university has listened courteously and has done nothing about my profound recommendations. Probably the inaction was sensible. Certainly it inched me a little towards a much needed humility. Just the same, the university has been good to me. It has been friendly and kind. It has given me freedom. It has permitted me to earn a reasonably good living. It has helped me, more important, to lead a satisfying life. I only hope that somewhere along the line I have helped some of its students to find a few of the things that make life worth living, the good things that made Faulkner believe that man will not merely endure but will prevail.

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INSTRUCTIONS FOR CONTRIBUTORS

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Although review articles are naturally most valuable to those researchers in the discipline with which the review is concerned, those outside the discipline may also benefit—but only if authors recognize that a scientist is somewhat of a layman outside his own field. Within such a framework, therefore, a review article can perform the following functions:

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- Stimulate research efforts.
- Evaluate existing and proposed research.
- Coordinate knowledge among administrators.
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LEAF PROTEIN RESEARCH

In the International Biological Program

N. W. PIRIE

DURING our lifetime the higher plants will probably become the main source of the extra food that the world needs. Algae, in normal circumstances, offer no advantages. Micro-organisms will be valuable for converting various wastes and byproducts into food, and they will be especially useful if the suggestion that they can be grown in edible form on coal and oil proves well founded. Chemical synthesis is not likely to be cheaper than agriculture as a method of getting protein or carbohydrate.

The food plants that are now grown extensively were all known to primitive man. They were chosen primarily because they gave some product—a seed or a tuber—that could be stored so as to tide over periods of drought or cold weather. With modern techniques of storage, this limitation no longer operates so strongly and choice can be wider. This means that leaves and immature flowers, which at present serve mainly to make meals more interesting rather than more nourishing, could play a larger part. Nothing but habit keeps this from being done in Europe and the United States. But in many parts of the tropics, the familiar vegetables do not grow well. Immigrants to these parts tend, therefore, to depend on imports, and the original inhabitants eat very little fresh vegetation.

Three courses could be followed to overcome this situation: (1) More vigorous efforts could be made to introduce the vegetables already used in South China and parts of Indonesia; (2) a wider range of temperate varieties, especially some varieties not found suitable in temperate regions, could be tested in the new environment to see whether they would flourish in it; and (3) selection and breeding could be started on the local plants. The last is the most interesting approach. It involves doing quickly with modern techniques the job that took centuries by the hit-or-miss methods of the mediaeval gardener. These things will indubitably be done but, even under ideal circumstances, vegetables are likely to supply only 2 to 5 percent of a person's daily protein intake. They do, of course, supply other nutrients besides protein. But protein deficiency is the world's most widespread dietary fault, so that attention may usefully be concentrated on it.

Leaves are the primary source of almost all our food but, because of the amount of fiber in them, they can be eaten only sparingly by people. Hence most plants are allowed to go on growing till protein has moved out of the leaves into seeds and tubers. Or they are fed to animals. We are accustomed to these altered forms and relish them, but

movement or conversion wastes time, or food, or both. As soon as this is realized, the advantages of making food from leaves directly by mechanical processes are obvious. This is a logical extension of well-established processes such as the extraction of sugar from cane or beet, and oil from olives or soya.

Work on the extraction of edible protein from leaves started 30 years ago; machinery suitable for large scale extraction was designed 20 years ago; and 10 years ago reasonably satisfactory units were working at Rothamsted. There are units—either made at Rothamsted or based on our designs—in India, New Guinea, Nigeria, Uganda and the United States. Machinery working on a more elaborate variant of the process was in use in Israel. Nevertheless, considering the potentialities of this method of making protein concentrates, especially in the wet tropics, the scale of research is still extremely small. The total effort devoted to research on leaf proteins is only a tiny fraction of that devoted to the preparation of palatable products from oil-seed residues, fish, yeast, algae and other microbial materials. This disparity in the scale of research should be born in mind when the quality of the different end products is being compared.

The extraction process is extremely simple. It is summarized in Table 1 and its historical development has been given in some detail elsewhere (*13*).[1] For large-scale (0.7 to 1.5 tons wet weight per hour) work we use a 25 h.p. pulper (*2*) that delivers the pulped leaf to a 1 h.p. press (*4*) which extracts the protein-containing juice. Seventy percent of the protein in young lush leaves can be extracted, and these soft leaves are obviously the easiest to pulp. We also use a smaller machine (*3*) that pulps 100 to 200 kg. batches of leaf and presses out the juice at the same time. Protein is coagulated by heating the juice quickly to 70° C. or higher (*12*); it is then filtered off in conventional equipment and washed. At this stage, it is a dark green cake with the consistency and perishability of cheese. We generally use protein in this form for cooking, but it can be preserved by drying, salting, pickling, or canning, and it can be extracted with solvents so as to make a gray-brown powder.

Feeding trials on pigs (*6*), rats and chicks (*5, 16*) infants (*15*), and rats (*7*)—all show that leaf protein undamaged through inappropriate drying methods has a food value as great as that of fish meal or the best seed proteins but less than that of casein or egg protein. Food value does vary, however, depending on the species and age of the leaf (*7*), for which no fully satisfactory explanation has as yet been offered.

Need for International Cooperation

WORK on leaf protein had reached this stage by the end of 1963, when, after a somewhat hesitant start which I have discussed elsewhere (*14*), the decision was formally taken to establish the International Biological Program (IBP). It seemed, for three reasons, that international cooperative research on leaf protein would be a suitable facet of work within the IBP.

[1] Italic numbers in parentheses refer to Literature Cited, p. 21.

TABLE 1.—*Pulped green leaves are separated into:*

Juice which gives after coagulation	coagulum containing	proteins fats starch	Food for man and other non-ruminants.
	fluid containing	amino acids amides sugars salts, etc.	Medium for the growth of micro-organisms.
Fibrous residue containing	most of the	cellulose hemicelluloses lignins pectin	Still a fodder for ruminants and a substrate for microbial fermentation.
	some of the	proteins fats starch	

1. The need for new sources of protein is most acute in countries with little capacity for doing the research and development needed before protein can be produced from novel sources.

2. Interesting research on plant physiology and agronomy is involved in the husbandry of the crops from which leaf protein would probably be made.

3. The presentation and acceptability of any novel food should be studied in as many environments as possible.

The International Sectional Committee for "Use and Management of Biological Resources" (UM) agreed in 1965 that the project was relevant to the IBP (*8, 11*) and it was one of the themes discussed at an IBP/UM Working Group meeting on "Novel Protein Sources" in 1966 (*9*).

Early in 1966 the Royal Society, acting on the recommendation of the UK National Committee for the IBP, made a grant for the design and manufacture of equipment with which the extractability of leaf protein could be measured on a laboratory scale in a consistent and standardized manner. This procedure is a necessary step in Phase I of the IBP, which is concerned with design and feasibility, for there is no reason to think that all the apparent differences in the extractability of protein from different plant species are real and not the consequence of the use of widely different extraction methods.

Protein Extraction

THE extraction of leaf protein consists of two processes: the disintegration of the leaf, and the expression of the protein-containing juice. A domestic meat mincer, either hand or power driven, has been used for so many years for making leaf pulps at Rothamsted and in other laboratories that we decided to use it in the first instance and study the expression of juice. It is already well known that the conventional screw press is not suitable; the mass of pulp in it is so thick that the fiber acts as an ultrafilter and holds back protein as soon as any significant amount of pressure is applied. Most of the measurements made hitherto have depended on hand squeezing in a cloth and they have established the broad outlines of our knowledge of suitable plants from which to make protein. There is, however, little prospect of getting consistent results with hand squeezing. There are uncontrolled variations in the amount of pressure applied, in the rate at which it is applied, and in the extent to which

the pulp is rearranged within the cloth during extraction.

When protein is being made on the large scale, the pulp is pressed between a smooth belt and a perforated roller. There is no differential movement between these two and the layer of pulp after pressing at 1.5 to 2.0 kg./cm.^{2} is about 5 mm. thick. Our press simulates these conditions and so should give results comparable to bulk production. We are well satisfied with the repeatability of the measurements made with this press. However, having got consistent pressing results, we are becoming increasingly dissatisfied with the domestic mincer as a means of making the initial pulp and we have begun to design a pulper that will, on 2 to 3 kg. samples of leaf, simulate the action of the large machine. If our grant is renewed in Phase II of the IBP, this pulper will be built.

Yields and Sources

EXPERIENCE with large scale extraction, accumulated up to 1964 (*1*), made it clear that 1 ton of extracted protein could be obtained from 1 hectare in 1 year at Rothamsted. Since then we have raised the yield to 1.3 tons; in India it is 3 tons because of the longer growing season. This, although a considerably greater yield of edible protein than can be got in any other way, is only the beginning. We are using those crops with which farmers are already familiar such as wheat, barley, rye, rape, tares, maize, kale, clovers, etc. These crops have been selected because of many qualities other than the ability to give a good yield of extractable protein. In Phase II of the IBP we hope that several institutes, in different climatic zones, will get laboratory-scale equipment similar to ours and make systematic measurements on different crops, harvested at different stages of maturity and after different fertilizer treatments, so as to work out a system of agronomy adapted to leaf-protein production.

Ideally, the leaves used would be the byproduct of some other form of production—cotton, jute or sugar—or would be unused weeds floating or growing round the edges of bodies of water where they could be mechanically harvested. Such plants would provide something for nothing but there would be little control over the quality of the starting material. In that way, an existing waste or the growth on extensive unexploited areas of water and swamp would be used. Less extensive areas of little used land lie along the margins of seasonal lakes and rivers. These often remain moist too briefly for them to carry a conventional crop through to normal harvest. They would be useful as a source of such leaves as can be harvested a month after sowing. Green manures and cover crops are already grown extensively; they are incompletely or inadequately used because, in hot climates, most of the protein in them is destroyed and denitrified by soil micro-organisms.

Without wishing to belittle the importance of these crops as a means for preserving soil texture, it may be suggested that the leaf residue after protein extraction would probably serve as well as the intact crop. This is a matter for experiment. In all these examples, custom or the physical condition of the area used for growth controls the species of plant that would be used. More freedom of choice is given when crops are grown primarily as sources of leaf protein, though, with the subsidiary prospect that the fiber residue would form the basis of a cattle fodder. The range of species worthy of study is immense. It is not limited to existing crop plants, so that the possibility exists of developing a new style of agriculture—especially in the wet tropics. Any leafy plant that grows, or is expected to grow, exhuberantly in a region is a potential protein source provided it is amenable to propagation, fertilization, and harvesting. This point is important: Ultimately, what is harvested will be what has been cultivated. This is not a method for using the sparse unmanured growth from unused land.

Future Prospects

INTEREST in leaf protein production and use was already being shown in other countries before the inception of the IBP—as the scattered distribution of extraction machinery shows. Under the IBP, research should become more systematic. At the suggestion of Professor Burström of Sweden, work on leaf protein is included in the Swedish IBP program and one of his colleagues worked with us on a grant from the UK/IBP committee. The IBP has not been long established in India, but two scientists have already come to Rothamsted on IBP grants to learn our methods, and we are making plans to start cooperative IBP projects at two centers there. Preliminary arrangements have been made for a similar project in Nigeria. We will be very willing to cooperate with any other country that wishes to start work.

Allocation of responsibility for different research projects within the IBP is, to some extent, arbitrary. The agronomic aspects of work on leaf protein could logically come within the compass of the section devoted to "Production Processes". A suggestion has been made (*10*) that a joint PP/UM subcommittee should be set up to consider the various ways in which plant proteins could be more adequately used. This committee would be a suitable parent-body to control leaf protein research. Similarly, when laboratory scale work has advanced so far as to make it reasonable to study bulk production within the framework of the IBP, intensive research on handling, presentation and acceptability will be needed. This aspect of the work has already been discussed informally with the section on "Human Adaptability" and a joint HA/UM subcommittee will probably be set up later. There is no reason why work on acceptability in any region should be delayed until production starts there. Proteins from many different leaf species have similar properties, and supplies for the initial trials can be sent from Rothamsted.

So little work has been done on leaf protein that confident predictions about future developments cannot be made. It is possible that the enzymic methods that we use in the laboratory will be preferable to mechanical methods of extraction. It is possible that, as with fish protein concentrate, it will be necessary to subject the product to more intensive and expensive refining before it is acceptable. Furthermore, it is quite likely that some of the other novel proteins will prove so amenable to local production that they will meet all local needs. Obviously, I do not think these things probable or I would not be working along present lines. One very important advantage of gaining the interest of the international biological program in the project is that these points should soon be settled.

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AGRICULTURAL DRAINAGE AND EUTROPHICATION

J. W. BIGGAR AND R. B. COREY

AGRICULTURAL drainage, like many other aspects of our total water resources, has only recently become of national interest and concern. This is particularly true as to the quality of drainage water and more specifically to nutrients in the drainage. As a result, relatively few studies have been directed toward elucidating the factors that control the amounts of plant nutrients reaching streams and lakes from agricultural sources. However, a number of investigators have studied nutrient losses from soils in conjunction with studies designed to measure salt movement and efficiency of fertilizer application or to clarify soil development processes. Results of many of these studies can be applied to the problem of eutrophication of lakes.[1]

Although the current emphasis is on man's contributions to water fertilization, we should not lose sight of the fact that all natural waters contain dissolved materials—plant nutrients included—derived from natural processes. For example, recent estimates of annual solute erosion in 11 western river basins ranged from loads of 180 tons per sq. mi. in the Willamette basin to 4.2 tons per sq. mi. in the Gila basin—an average of 58 tons per sq. mi. The average dissolved solids content ranged from 54 to 1,500 p.p.m. Quantities of solutes eroded are highest in areas of abundant precipitation and runoff whereas solute concentrations are highest in areas of low precipitation. In contrast, the greatest suspended sediment losses occur from areas of intermediate effective precipitation.

Although many substances, both inorganic and

[1] Eutrophication is the excessive fertilization of waters with nutrients, notably nitrogen and phosphorus, which ultimately result in the degradation of the material beauty and usefulness of the waters. Both natural as well as manmade causes contribute to eutrophication.

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organic, contribute to the growth of algae, nitrogen and phosphorus are the only ones that have been definitely established as consistent growth-limiting factors in natural waters.

NUTRIENTS IN THE SOIL-WATER SYSTEM

MOST of the soluble nutrients that get into lakes and streams from rural areas are first dissolved in water and then moved in solution to the waterways. Some nutrients may also be carried to streams and lakes as components of suspended particulate matter and later may be converted to soluble forms. Therefore, to fully grasp the problem of water fertilization from agricultural land, it is necessary to understand the factors that affect the forms and solubilities of the nutrients and the manner in which the nutrients are transported to the streams and lakes.

Forms and Amounts of Nitrogen and Phosphorus

FROM an agronomic viewpoint, some sources of nitrogen that ultimately contribute to eutrophication are relatively unimportant. Nitrogen from rainfall may average 7 or 8 pounds per acre per year. This is not enough to produce marked increases in crop yield, but in runoff or percolative waters it becomes a steady significant supply. Quantities of N fixed by plants and micro-organisms also contribute to the potential source of available N for redistribution. Hence 200 pounds of N per acre per year might be fixed by legume-micro-organism interactions in comparison to 10 to 30 pounds under grass. Nitrate is the form of nitrogen most subject to leaching. But this does not exclude the possible movement of certain organic forms which may be quite soluble.

The phosphorus content of soils may vary from 0.01 to 0.13 percent. It occurs both in organic and inorganic forms, neither of which is considered to be very soluble. Proportions of each kind range from 3 percent organic and 97 percent inorganic to 75 percent organic and 25 percent inorganic.

Inorganic forms are mainly iron and aluminum phosphates in acid soils and calcium phosphates in alkaline soils. All inorganic forms of phosphate in soils are extremely insoluble, and any phosphorus added as fertilizer or released by decomposition of the organic matter is quickly converted to one of these insoluble forms. Because of the extreme insolubility of these phosphates, the overall concentration of soluble phosphorus in the soil solution of surface soils seldom exceeds 0.2 mg./l, and concentrations in the range of 0.01 to 0.1 mg./l are common.

Soluble Nitrogen and Phosphorus in Surface Runoff and Percolates

CONCENTRATIONS of nitrogen and phosphorus in surface runoff are considerably different from those in soil percolates. The ammonium and especially the nitrate forms of nitrogen are very soluble. If these materials are present at the surface of the soil at the beginning of a rain, the first rain that falls will dissolve them and carry them into the soil. If the surface runoff occurs later, there will be little soluble nitrogen left at the surface to be carried away with the runoff. Therefore, runoff waters usually have very little soluble inorganic nitrogen. In fact, the nitrate content of runoff water is usually lower than the average nitrate content of rain water. This condition is due to the fact that the first rain that falls sweeps most of the nitrate from the air and carries it into the soil. Rain that falls later and runs off has a lower nitrate content.

Although runoff waters in humid areas contain relatively little nitrate, this is not necessarily true of the water which percolates through the soil. As stated before, nitrate is completely soluble in the soil solution and moves with it. If the nitrate ions manage to evade absorption by the plant roots as they move downward, they will be present in the drainage waters which move to the lakes and streams by base flow. Thus, soil percolates generally have higher contents of nitrate than do surface runoff waters. This nitrate eventually reaches the waterways unless the water emerges in a marsh where it may be absorbed by the vegetation or converted to gaseous nitrogen because of reducing conditions.

Relative concentrations of soluble phosphorus in surface runoff and soil percolates are just the reverse of the nitrogen system. Application of phosphorus to the surface of the soil tends to saturate the "fixing" sites at the surface and locally raise the concentration of phosphorus in the soil solution. This is a near equilibrium system, and although infiltrating waters will carry the soluble phosphorus

downward, more will quickly dissolve to maintain the concentration in solution. Runoff water will contact this surface soil, and the phosphorus concentration in the runoff could conceivably approach the equilibrium concentration. If phosphorus fertilizers were applied to the soil surface, the equilibrium concentration of phosphorus in a thin surface layer could reach 1 mg./l or more and the concentration of phosphorus in the runoff water might range up to a few tenths of a mg./l. This is speculative, at best, since there are few data available that pertain directly to this problem. However, soluble phosphorus concentrations in surface runoff frequently approach or exceed the average concentrations expected in the soil solution—which tends to support this contention.

In the water which percolates through the soil, the soluble phosphorus concentration is usually very low because the phosphorus gets precipitated in the subsoil. Therefore, most of the soluble phosphorus should reach the waterways via surface runoff. In contrast, most of the soluble inorganic nitrogen should reach the waterways mainly by percolation and base flow. These conclusions assume that the soils are not frozen. If the soils are frozen, a relatively large proportion of all soluble nutrients at the soil surface would be carried away in runoff waters. This is undoubtedly true during the initial stages of the spring thaw, and is of special significance for nutrients in manure or fertilizers applied on frozen fields.

Effects of Suspended Material

SUSPENDED materials, whatever their source, undoubtedly affect the nutrient status of water; however, there are no data available to estimate the magnitudes of their effects.

Nitrogen in suspended particles is mainly organic. Some of these particles will sediment out when the water velocity decreases, to be covered later by other sediments so that they do not contribute significantly to the soluble nitrogen supply. Other organic particles may be attacked by micro-organisms; the nitrogen is converted to soluble inorganic forms in the decomposition process. Fresh organic materials are quite readily decomposed by micro-organisms, but humified soil organic matter is quite resistant. Thus, the contribution of the suspended organic matter to the soluble nitrogen content will depend on the nature of the organic materials.

Phosphorus in suspended particles is both organic and inorganic. Organic forms would undergo the same reactions as nitrogen; however, the inorganic forms present a more complex system. Phosphorus bonded to iron, aluminum, or calcium in the mineral particles tends to equilibrate with the phosphorus in solution. If the particles come from a surface soil high in phosphorus, they will tend to support a relatively high concentration of phosphorus in solution. On the other hand, if the particles come from a subsoil low in phosphorus, they will support a low concentration of phosphorus in solution. In fact, if subsoil particles were introduced into a stream containing a moderate or high concentration of soluble phosphorus, they would adsorb phosphorus from the water, thereby lowering the phosphorus concentration in solution. Since much of the sediment in streams during high flow is frequently derived from stream bank erosion, the phosphorus status of the sediments in the stream beds and stream banks may well be an important factor affecting the concentration of soluble phosphorus in the water during periods of high flow.

Depending upon the nature of the suspended materials, the contribution of eroded particulate matter to the nutrition of the algae may be associated more with its effects on the concentrations of soluble nitrogen and phosphorus in the incoming waters rather than with the total or "extractable" nitrogen and phosphorus in the particles themselves.

Other Constituents

CONSTITUENTS in drainage water other than nitrogen and phosphorus are known to be required for adequate lake fertility. Deficiencies of nutrients may occur and sometimes are added for greater production. Most, if not all, of these constituents are found in soils and the parent materials from which the soils are derived. Cations such as Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} are often present in major proportions. Further assessment of the sources and nature of many of the trace elements in agricultural drainage water will require additional investigation.

DISPOSITION OF AGRICULTURAL DRAINAGE

PRECIPITATION from the atmosphere reaching the soil surface is disposed of by (1) surface runoff, (2) ground water runoff (interflow), (3)

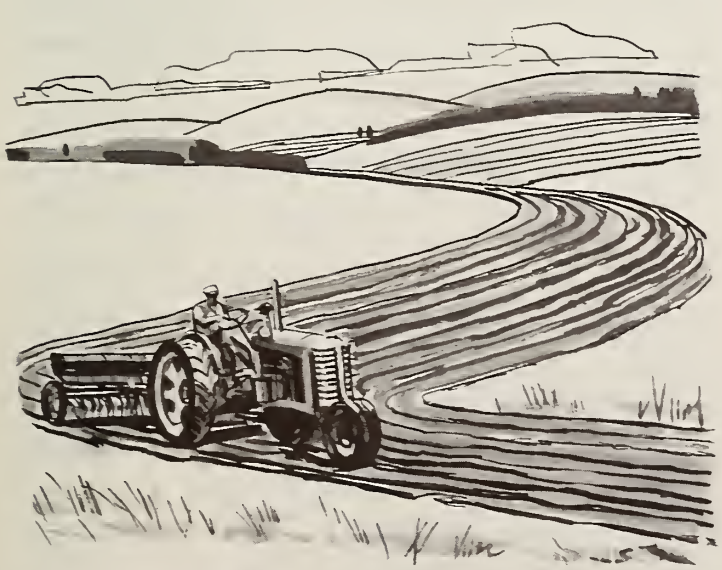
deep percolation, (4) storage, (5) evaporation and transpiration. The first three of these can and do contribute to eutrophication by providing pathways of nutrient movement to the lakes and streams. Water that does not run off or evaporate from surface catchments infiltrates the soil. Some of this water percolates down into deeper layers, eventually joining the ground water, and many rivers and lakes receive a major portion of their water from ground water flows. A portion of the water that enters the soil drains down slope to reappear at a lower elevation as surface water or seepage. This water may also contribute fertility to the lakes.

Other processes in the hydrologic cycle indirectly contribute to changes in the fertility load of the water. Some precipitation is intercepted by the plant canopy and returned to the atmosphere by evaporation. In addition, water that is evaporated may return salts to the surface where they may be lost by runoff and seepage or redistributed in the profile with the next water application. Transpiration reduces percolation losses, thereby modifying nutrient movement patterns.

Irrigation water, which represents a recycling of the water derived from runoff, seepage and percolation, often increases the amounts of nutrients moving to lakes and streams.

Surface Runoff

WHENEVER precipitation occurs more rapidly than it can be absorbed by the soil, it runs off into drainageways or into depressional areas. Because of the importance of surface runoff to streamflow and erosion, much effort has been expended to predict the quantity of both runoff water and suspended matter—usually without regard for the chemical or physical nature of the soluble or suspended materials.



Very little is known about the changes in chemical composition of the discharge resulting from runoff and seepage. In some ways, nutrient losses from an agricultural area should be easy to estimate because of our knowledge of soil characteristics and crop uptake. But on the other hand, the large diversity of soil and vegetative conditions under a system of cultivation adds to the complexity of the problem.

Infiltration and Percolation

OBVIOUSLY, the processes of infiltration and percolation are interrelated with runoff and rainfall. Water that is not otherwise lost from the soil infiltrates and percolates sometimes to shallow depths from which it may reappear as ground water seepage (interflow) at the surface or it may percolate to perched water tables or deeper underground aquifers. Since the replenishment of soil water and ground water depends on the infiltration and percolation processes, considerable study has been devoted to them. Likewise, methods for increasing infiltration have been sought in order to reduce runoff and related erosion problems.

It is quite evident that an understanding of infiltration and percolation theory (and particularly its application) could provide useful predictions—not only of the disposition of drainage waters, but also of expected nutrient removal by combining water flux estimates with the mixing factors that determine nutrient distribution within the soil-water system. Although recent reviews have outlined the extent of our progress in the development of the theory of soil water movement, it is significant to note the lack of application of these theories to the prediction of water movement both in cultivated soils and natural watershed conditions.

Maximum percolation rates are established while water is being applied to the soil surface. When application ceases, infiltration no longer takes place, but water continues to move in the profile. In general, a decreasing water content at any point in the profile is accompanied by a decreased rate of water movement. Even though less water is moving

through a given depth, the nutrient redistribution continues. The rate of water movement may become very slow and if it ceases, nutrient movement over long distances also ceases. Rapid removal of water in the root zone by crops minimizes downward loss of both water and nutrients during certain periods of the year. Below the root zone, the water movement is not complicated by plant withdrawal, so that the soil may continue draining. The nature of nutrient movement throughout the entire range of water fluxes that occurs in soils requires additional study. Furthermore, it would be helpful to ascertain the minimum rate of water movement beyond which there is little significant movement of nutrients.

Ground Water

WHEN nutrients percolate to the ground water, their subsequent movement to lakes or streams involves the general ground water movement. Because many of our water supplies are derived from ground water, the velocity and direction of water movement as well as the quantities are investigated when possible. The importance of understanding the mixing between the resident ground water and replenishment water is readily apparent, particularly if the invading water contains undesirable dissolved constituents.

The mixing will be very different in a deep sand aquifer as compared to that in fractured limestone. Thus, extensive dilution between source and discharge may occur in the former, while in the latter—although the path may be tortuous—the amount of mixing with resident fluid will be small. In a deep aquifer, complete mixing is probably rare. It is not uncommon to have layers of more dense or less dense fluid flowing over and under each other. Therefore, it is not safe to assume that nutrients derived from percolating waters will be diluted by the entire ground water mass prior to discharge into a lake.

The velocity of ground water movement may vary from as little as 1 foot per year to several miles per month. Displacement of all the water from a particular aquifer may take several hundred years, even though parts of the aquifer may be readily conducting water. Continuing investigations of ground water movement and mixing are needed.

Nutrients in Percolate Waters

DESPITE recent rapid advances in the development of water movement theory, this theory has not been extensively used to describe nutrient movement. Many studies, however, indicate that loss of nutrients by leaching is a significant pathway for fertilization of lakes.

Contrary to previous thoughts, water and its dissolved constituents do not move in a one to one manner. There is sufficient evidence now to indicate that the mixing that occurs between the resident soil solution and invading water either from precipitation or irrigation must be considered as a major process affecting the movement and distribution of soluble materials both in the plant root zone and beneath it. Hence, the processes of mixing will determine the concentration changes that occur as a function of both time and direction of flow. The reason for this is evident when we realize that (1) dissolved constituents can move independently of the solvent, and (2) macroscopic parameters, such as hydraulic conductivity, cannot describe processes which are responsible for mixing on a microscopic scale.

On a microscopic scale, soils are made up of particles of various shapes and sizes. In like manner the spaces between the particles are of varying shapes and sizes—giving rise to channels that vary in direction, size, and shape. Through these channels or pores water moves; the channel is sometimes completely full of water with no air space and at other times only partially full of water. As a result of the variability in the paths of flow, water moving through these pores changes direction and rate from point to point. Consequently, a band of water containing a dissolved constituent, when introduced into a system of microscopic channels conducting water at various velocities, soon becomes spread out or diffuse. The length of the diffuse zone increases more or less as the square root of the distance traveled and is affected by the velocity. Mixing therefore takes place between the resident solution and the invading solution. Other interactions between the invading solution and the solid matrix also modify the distribution of the constituent. Ions such as ammonium or phosphate may undergo exchange or adsorption and may be "delayed" in their movement in the direction of fluid flow. Anions such as nitrate or chloride which are usually not adsorbed may be repelled by the solid matrix so that the volume available for water flow is different from that through which the negatively charged ion moves.

On the other hand, the adsorption of water by the matrix, and the accompanying modification of its physical properties, especially viscosity, may reduce the area of effective flow and create a variation of velocity within the cross-sectional areas of a pore.

Not to be overlooked is the process of diffusion of the dissolved constituent that can occur as a result of activity gradients within the soil-water system. Although not a spectacular process, it is inevitable, and it is likely to contribute to mixing at flow velocities comparable to those found in many soils and some aquifers. Diffusion cannot be expected to move large quantities of salts long distances in short times, but it can move large quantities of salt short distances in any given time span.

Although it would be helpful to be able to predict the movement of dissolved constituents based on the water movement, it might prove to be more useful to predict water movement on the basis of the movement patterns of dissolved constituents. An example of this approach includes the use of isotopes and labeled salts as tracers.

Significant increases in nitrates in ground waters from domestic and agricultural activities seem certain. Recycling of the water through irrigation apparently results in further concentration of nitrates. The nature of the water and nutrient movement with respect to soil stratification, however, remains unclear.

Nutrients in Runoff Waters

APART from the difficulties of predicting the quantity of runoff from storms, the chemical composition—and particularly the nutrient content—of the runoff is not well known. Catchment basins have provided data on the total sand, silt and clay (suspended solids) loads that accompany a particular volume of runoff. Usually, the mineralogical characteristics are not measured and rarely are fractions considered. Both colloidal and dissolved fractions should be considered.

Nutrients in Eroded Materials

DATA relating the effect of sediment loads to the nutrient status of receiving waters is not well-documented. Suspended solids include both sediments and material of a colloidal nature that remains suspended in lakes and rivers.

A large number of reports giving the quantities of sediments removed by water erosion at various locations around the world emphasize the varied conditions that give rise to these losses. Separation of nutrients carried off in solution in runoff water as compared to those associated with sediment is difficult and makes identification of the source of nutrient arbitrary. Therefore total analysis of nutrient losses in sediments does not reflect that which is in solution and that which is adsorbed—a distinction which could be very useful.

Nutrient losses by erosion tend to be selective in the sense that organic matter and clay particles, which in soil are relatively high in nutrients, are more subject to erosion than coarser particles.

That eroded material frequently differs in composition from the original soil is good evidence that erosion losses will bring about nutrient changes in receiving waters.

Phosphorus losses in eroded material may be much more significant than nitrogen in relation to other avenues of loss. Phosphorus is relatively immobile, tending to reside where it is placed. Since practically all of the phosphorus is held in an immobile form, it is not leached as is nitrate. Placing phosphorus fertilizer beneath the soil surface avoids immediate loss by erosion but later cultivations may expose it to runoff.

Much of the material that is eroded probably is not measured in catchment areas. Consequently, the colloidal reactive phase in soils that is eroded (including organic matter) is not evaluated. These fractions may be significant in eutrophication of lakes. It would be useful to have measurements that consider all parts of the eroded material and the chemical changes involved.

The fact must not be overlooked that sediments and related materials not only contribute nutrients by releasing them to the receiving waters but also they may adsorb or fix nutrients. An eroded colloidal soil, low in phosphorus, might remove measurable amounts of phosphorus from water, provided there was sufficient mixing to bring the sediment in contact with large volumes of water. By the same reasoning, all nutrients which potentially might become available to lakes and streams from suspended sediments entering the water may not become available because they are deposited and buried under later sediments.

Apparently not all the nitrogen lost to streams ends up as nitrate. However, it is also probable that nitrate analyses underestimate the total nitrogen

contributing to eutrophication. Consequently if an average figure for NO_3–N must be used, it might safely lie between 1 and 10 pounds per acre per year, realizing that much of this is derived from subsurface flows.

The problem of estimating phosphorus losses significant to eutrophication is even more difficult. Total phosphorus losses, mostly through erosion, range from near zero to about 20 pounds per acre per year. Losses of soluble plus hydrolyzable P range from 0.04 to 2 pounds per acre per year.

Agricultural Drainage to Lake Mendota

ON the basis of agricultural drainage studies in the Lake Mendota (Wisconsin) watershed, it would appear that different methods of manure disposal could significantly reduce the N and P inputs from agricultural drainage. Undoubtedly much of the nitrate content of ground waters arises from agricultural lands, but it is difficult to evaluate the effects of management practices because of our limited knowledge of nutrient sources and flow characteristics of percolating waters.

NEEDED RESEARCH

IT seems reasonable to conclude that a number of investigations would provide immediate and long-term benefits in understanding the contributions of agriculture to eutrophication. Characterizing the chemical and mineralogical contents of runoff waters over a period of time would be most useful. Changes in these constituents, as they progress from the point of origin to their deposition in lakes and streams, would be essential. These changes, in turn, can be related to soils, crops, rainfall, runoff, and storm characteristics.

Continued effort should be made to understand the nature of ground water movement and the mixing of contaminating zones into these flows. The transport of water in the unsaturated zone between the surface and the ground water, particularly below the root zone, should receive more study. Such studies should encompass the movement of nutrients, including the various forms which are yet unknown. Relating these movements to the intermixing with ground water flows has received very little study. Not only more data but improved physical models of nutrient losses runoff, erosion, and percolation should be sought so that agricultural drainage contributions to eutrophication of lakes and streams may be more accurately assessed and corrected.

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OF HUSBANDRY AND HEALTH

DISEASE is a weakness which the world's livestock industry cannot afford. It not only costs countless millions of dollars but it impedes progress in that essential industry to a degree which is often poorly appreciated even by specialists.

It is a salutary experience for a group of research workers to witness an experimental herd of cattle, whose output is being carefully boosted and minutely recorded, going down with foot-and-mouth disease. "Going down" is a good colloquialism. The animals go down rapidly in condition, their milk yield goes down spectacularly overnight, and they themselves go down in the physical sense. The tender, raw patches on their feet make moving and even standing still extremely painful.

Foot-and-mouth disease is usually spectacular. You can see it. Blisters on and under the tongue and round the palate leave raw slough areas which make mastication agony. The affected animal is lame, and all four feet are acutely sore. The temperature soars. The coat looks as if it had been brushed the wrong way. The results of the disease can be equally spectacular. It may upset months of carefully prepared experimental work, which is excessively annoying to the scientist. It can effectively prevent the preparation of paddy land by incapacitating draft animals for a few vital weeks, which can be a major tragedy for the peasant. The incidence of foot-and-mouth disease is spectacular. If, at the present time, you were to dip a brush in red ink and, on a world map you shaded in those areas in which this disease is widespread, you would have a chart in which a wider area would leap to the eye than used to be covered by the imperial red of the British Empire—or indeed, of any other empire.

Unfortunately, the only thing which is not spectacular about foot-and-mouth disease is its death rate. Unfortunate? Yes, in the sense that if the percentage of affected animals that died was substantially higher than the customery average of 5 or 6 percent, something very drastic would have to be done to control the disease.

It is certainly one of the diseases of greatest economic importance in the world, but the loss in milk, in meat, in draft power, in abortion and reduced reproductivity is not always immediately apparent. This is especially true in countries where the disease has always existed and where people have apathetically accepted it as they accept floods and earthquakes and other manifestations of the unpredictable malice of the gods.

Rinderpest is quite another matter. It kills and therefore it must be fought. It is being fought in every land where it occurs. Its importance can be assessed by the fact that in Vietnam, which has suffered for more than 20 years a bloody and devastating war, nothing has been allowed to check the vaccination campaign—not the disruption of agriculture, not the destroyed paddy areas, not the many veterinarians and vaccinators killed or reported missing. It is not inappropriate to commend here the dedicated livestock and veterinary services of that war-torn country for their courageous devotion to duty—and the support which they have been receiving from USAID. Some day, when peace comes, there will be something on which to rebuild.

India, which surely has much more than her fair share of troubles, threats, hunger and poverty, has an appalling problem in livestock disease. Foot-and-mouth has been, on many occasions and for quite long periods, a major preoccupation of my professional life. I have had to deal with it in many countries and under many different conditions, and I have seen many animals affected, many vaccinated,

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and many slaughtered. In India, slaughter and vaccination are not, as yet, possible. In 3 weeks in that troubled land early in 1966 I saw more foot-and-mouth disease than in my entire career to date. I believe that it must be numbered among the greatest of India's many great problems.

And not only India. The direct effects of the seven recognized virus types and of the strains within these types are bad enough. The indirect effects have an extremely costly impact on those advanced countries such as the United States of America and Australia, which are spending enormous sums of money on quarantine and related services in a determined effort to keep the disease away from their livestock, or if the worst happens, to be in a position to contain and eradicate the disease as soon as it appears.

In Europe, which for many years has harboured foot-and-mouth disease in widely scattered areas and which has experienced fairly regular epizootic cycles every 7 to 10 years, the post-war period has seen a concerted and highly successful control campaign. This has been based upon the general application of sanitary measures—which again come under the all-embracing heading of quarantine—and a wide extension of vaccination. In several countries the concept of vaccination till the incidence has been reduced sufficiently to render compulsory slaughter and stamping out economically practicable, has been achieved. Great Britain, which rightly has restricted its control measures to a stamping out policy has reaped a considerable bonus from the new continental policies. Foot-and-mouth disease, which used to be an annual purgatory for farmers and veterinary officers, has only occurred once in a 4-year period. The single outbreak occurred in the south of England in April 1965. It was successfully stamped out. This extraordinary degree of freedom in an island country which has to import great quantities of livestock products has been due to the general reduction of incidence in Europe, a ban on the importation of pig meats from South America, and unremitting vigilance in quarantine.

Now the fat is in the fire again—not an inapt image! Denmark, Sweden, France, Netherlands, Germany (East and West), Belgium, Poland, Czechoslovakia, Hungary, Austria, Switzerland, Spain and Yugoslavia have all reported an increased incidence of varying degrees from minor occurrences to major catastrophes.

A variant of Type A virus has become superimposed on those constituting the costly epizootic in Turkey and has stepped up the threat to Europe. It swept through Turkey in 1965, complicating immeasurably the control measures which have been applied unremittingly since 1962. The buffer zone—the glass wall of vaccination separating Turkey from Europe—required as a minimum 1 million doses of trivalent (O/SAT 1/A) vaccine during the first half of 1966. In Europe we are not unaccustomed to walls of various types. This is one which we watch most anxiously, with hopes for its continued efficacy. It has been erected and is being maintained by a remarkable example of international coopera-

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On the morning of October 25, 1967, a British veterinarian received an urgent telephone call from a farmer living 4 miles south of Oswestry near the Welsh border. A few of his pigs, the farmer reported, appeared to be ill. When the veterinarian arrived at the farm, he found 12 of the animals had lesions that looked suspiciously like those of foot-and-mouth disease. The official diagnosis confirmed his first appraisal; the dreaded disease had once again gained entry into the British Isles.

Thus began Britian's worst outbreak of foot-and-mouth disease of this century. Within a month, more than 1,000 individual outbreaks had occurred. As this issue of *Review* went to press, the slaughter policy was being rigorously applied and 204,000 cattle, 97,000 sheep, and 112,000 pigs had been killed and destroyed by burning or burial. The affected areas, all in England, were well defined and contain a cattle population of approximately 4 million. Up to press time, no outbreaks had occurred in Scotland or Ireland, while in Wales only the border areas had become affected.

One factor that has made the outbreak so difficult to control is that virus Type O is involved—a strain with a particularly marked spreading characteristic. In one 5-day period—November 23–27—daily outbreaks were 76, 81, 69, 80, and 55.

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tion. It is protecting the countries of Europe, and also those countries far removed from the immediate red-shaded zones, from a spillover of virus which could be disastrous to livestock industries everywhere.

In the autumn and winter of 1965 wide areas of the USSR were affected with this "new" variant, further complicating a situation which was already complicated by the presence of the virus types A and O.

Just how complicated the pattern of control is can be appreciated when we consider that vaccine against one type of the virus does not protect against any of the other types. There are even immunological differences between strains of the same virus type.

And what of rinderpest, the ancient bogey of livestock, the "black death" of cattle? There are widespread and continuing and costly campaigns against this scourge in Africa and India and the Far East. Wherever it occurs it is being fought—and it still fights back with much of its old ferocity. Setbacks, such as that experienced in India early in 1965, are not uncommon, but the disease is slowly and painfully being controlled in a long-term, far-sighted series of campaigns which, when looked at collectively, hold some hope for the eventual eradication of the disease. Not, perhaps, in our time but quite possibly within the next century or so—which will still be a notable if long-postponed success.

The diseases of man and of his animals and those that are common to both animals and man form a serious impediment to the increases in production which are so vitally necessary to the world of today and of tomorrow. Any consideration of husbandry and health must have regard to the positive increases in output which can only result from better nutrition, better breeding practices, better management—and a decisive reduction in the enormous losses caused by disease. Animal husbandry, after all, means simply the care and use of livestock.

Disease is not always spectacular, is not even invariably obvious. Many millions of animals—and many millions of human beings—go through life in a state of subhealth with inapparent illnesses which shorten existence and make it miserable but which are so common, so widespread and so historical that they are accepted as the norm.

The universal insidiousness of the infections and infestations in the wide and sombre spectrum of parasitism alone constitutes a picture of despair and a challenge to modern technology. We know how to control many of the worst and most damaging of them: we have the knowledge but lack the logistics, we know the strategy but lack the tacticians.

We estimate that there are about 1,000 million cattle and buffaloes in the world, almost the same number of sheep, 551 million pigs, and innumerable goats and poultry. There are not more than 200,000 qualified veterinarians to cope with this vast general practice and many fewer specialists in husbandry and nutrition. A large part of this small cadre of skilled men is concentrated in the richer countries. They are helping those countries to grow richer, while the gap between the have's and the have-not's of the world grows irreparably wide.

The picture is grim but not hopeless. There is an increasing trend for the governments of the wealthy, advanced countries—the terms are not always synonymous!—to make available ever more of their specialists for work in the international field. There are indications, fostered by such movements as the Freedom from Hunger Campaign, of an awakening world conscience, of an acceptance of the fact that this is one world, that it is our world and our responsibility. There are signs that industry is joining science in helping not only to make the living standards in wealthy countries better but also to raise the standards in great areas of the earth's surface.

The underdeveloped countries of today are the developing countries of tomorrow or the day after tomorrow. The needs are immense and urgent. Will the challenge be accepted with sufficient force to make an impact on progress, or is the world, with all its resources, its vast potentials, and its high hopes, to accept the fact forever that hunger and poverty cannot be defeated?

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